The Economic, Energy, and GHG Emissions Impacts of Proposed 2017–2025 Vehicle Fuel Economy Standards in the United States

Valerie J. Karplus and Sergey Paltsev

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The Economic, Energy, and GHG Emissions Impacts of Proposed 2017-2025 Vehicle Fuel Economy Standards in the United States

Valerie J. Karplus*† and Sergey Paltsev*

Abstract

Increases in the U.S. Corporate Average Fuel Economy (CAFE) Standards for 2017 to 2025 model year light-duty vehicles are currently under consideration. This analysis uses an economy-wide model with detail in the passenger vehicle fleet to evaluate the economic, energy use, and greenhouse gas (GHG) emissions impacts associated with year-on-year increases in new vehicle fuel economy targets of 3%, 4%, 5%, or 6%, which correspond to the initially proposed rates of increase for the 2017 to 2025 CAFE rulemaking. We find that across the range of targets proposed, the average welfare cost of a policy constraint increases non-linearly with target stringency, because the policy targets proposed require increasingly costly changes to vehicles in the near term. Further, we show that the economic and GHG emissions impacts of combining a fuel tax with fuel economy standards could be positive or negative, depending on underlying technology costs. We find that over the period 2015 to 2030, a 5% CAFE policy would reduce gasoline use by about 25 billion gallons per year, reduce CO_2 *emissions by approximately 190 million metric tons per year, and cost $25 billion per year (net present value in 2004 USD), relative to a No Policy baseline.*

Contents

1. INTRODUCTION

Policymakers in the United States have proposed increases in the Corporate Average Fuel Economy (CAFE) Standards for new 2017 to 2025 model year light-duty vehicles.[1] The new standards will require that automakers deploy technology strategies to achieve a sales-weighted average new vehicle fleet fuel economy by manufacturer that is equivalent to a specified target. Although the stated goal of the standards is to reduce petroleum use and greenhouse gas (GHG) emissions, achieving this goal depends on many factors in addition to automaker compliance, such as demand for travel, the composition of the fuel supply, the rate of vehicle fleet turnover, and the carbon content of the fuel. Quantifying the range of future vehicle energy use and GHG

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[1] Light-duty vehicles include cars, pickup trucks, sport utility vehicles (SUVs), and minivans.

emissions, most of which takes the form of CO_2, under varying levels of policy stringency is an important task for policymakers. This analysis has relevance for the large number of countries and regions that have implemented or proposed fuel economy standards (An and Sauer, 2004).

It is important to understand how the incentives created by the CAFE Standards translate into reductions in gasoline use and CO_2 emissions by affecting vehicle characteristics, fuel use, and demand for travel. The CAFE Standards focus on new vehicles, but affects the prices of both new and used vehicles, rates of fleet turnover, vehicle travel by lowering the per-mile cost of travel, and ultimately, the average fuel use per mile of the U.S. fleet (Stavins, 2006; Small and Van Dender, 2007). Identifying potentially offsetting effects (such as the rebound effect) on policy effectiveness caused by responses in parts of the system unconstrained by policy is critical to obtaining a realistic picture of policy outcomes. It further helps inform design of policies to minimize these offsetting effects. One commonly cited factor that detracts from the CAFE Program's efficacy is the rebound effect—increased demand for travel in response to a lower fuel cost per mile. Taxing fuel has been suggested as one option for offsetting decreases in cost per mile (MacKenzie, 2009). As part of this paper, we consider the effect of combining a fuel economy standard with a modest fuel tax that is intended to encourage consumer demand for higher vehicle fuel efficiency, taking into account price feedbacks and interactions across sectors in a general equilibrium framework.

This paper is organized as follows. The second section describes the CAFE Program in the context of recent U.S. policy, the modeling framework used in this analysis, and the implementation of a fuel economy standard together with a gasoline tax in the model. The third section describes an analysis of the CAFE Standard alone under alternative technology cost assumptions. The fourth section describes the effect of combining the CAFE Standard with a fuel tax, and explores the sensitivity of the outcomes to advanced vehicle technology costs.

2. BACKGROUND AND MODEL DESCRIPTION

2.1 The U.S. CAFE Program

Fuel economy standards are a longstanding feature of the energy policy landscape in the United States. Passed in 1975 to reduce gasoline use in the wake of 1973 Arab Oil Embargo, the CAFE Standards mandated increases in the on-road fuel economy of cars and light-duty trucks starting in 1978 (EPCA, 1975). These standards were tightened sharply through the early 1980s but remained constant through much of the 1990s and were not increased again until 2005 for light trucks and 2011 for cars (Shiau *et al.*, 2009). In 2010, following classification by the Environmental Protection Agency (EPA) of CO_2 as a pollutant under the Clean Air Act, the EPA became involved in setting per-mile emissions standards for new passenger vehicles, which were harmonized with fuel economy measures under the CAFE program. A 2010 rulemaking mandated an increase in the combined average fuel economy to 35.5 miles per gallon (mpg) in

2016.[2] The stringency of standards in the next compliance period has been under discussion. For the model year 2017 to 2025 standards, several rates of year-on-year fuel economy increases were initially considered: 3%, 4%, 5%, and 6%, corresponding to 2025 mpg targets of approximately 46 mpg, 51 mpg, 55 mpg, and 60 mpg, respectively (EPA and NHTSA, 2010). In November 2011, the new proposed rulemaking issued by the EPA and NHTSA targeted a 5% year-on-year increase in the fuel economy of new cars for model years 2017 to 2025, while for light trucks an increase of 3.5% year-on-year is required for model years 2017 to 2021 and then a 5% increase for model years 2022 to 2025, for a combined light-duty fleet new fuel economy average of 54.5 by model year 2025 (EPA, 2011). The new standard will also likely include a number of provisions that would allow automakers to gain credit for early deployment of advanced technologies, trade credits across manufacturers, and introduce further flexibility into the timing and stringency of the CAFE requirements.

A number of previous studies have focused on effective design of energy and climate policies for light-duty vehicles, and on the CAFE Standard in particular. With increasing discussion of tighter CAFE Standards over the past ten years, a number of studies have investigated the cost effectiveness of these proposals and their total impact on energy use and CO_2 emissions (Bezdek and Wendling, 2005; Cheah *et al.*, 2010; DeCicco, 2010; EPA, 2010: Whitefoot *et al.*, 2010). These studies in turn built on previous analyses of the CAFE program (Goldberg, 1998). Studies vary in the extent to which they consider responses to the fuel economy constraint endogenously when modeling potential effects. Our approach here is to embed a technology-cost based representation of vehicle improvement potential in a macroeconomic framework that considers the broader energy system as well as fuel and vehicle price feedbacks to demand for light-duty vehicle transport.

2.2 The Passenger Vehicle Transport Sector in the EPPA5-HTRN Model

The model used in this analysis is a specialized version of the MIT Emissions Prediction and Policy Analysis (EPPA) model that includes a technology-rich representation of the passenger vehicle transport sector. The EPPA model is a recursive-dynamic general equilibrium model of the world economy developed by the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology (Paltsev *et al.*, 2005). The EPPA model is built using the Global Trade Analysis Project (GTAP) dataset (Hertel, 1997; Dimaranan and McDougall, 2002). For use in the EPPA model, the GTAP dataset is aggregated into 16 regions and 24 sectors with several advanced technology sectors that are not explicitly represented in the GTAP data. Additional data for greenhouse gases (carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6) are based on U.S. EPA inventory data and projects.

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[2] The CAFE Standard requires that manufacturers achieve 34.1 mpg average test-cycle fuel economy, if improvements in the air conditioning system are used to lower CO_2 emissions. The target of 35.5 mpg is equivalent to achieving the 250 grams per mile target through improvements in fuel economy alone.

To simulate the costs and impacts of policies, models must include broad sectoral coverage and macroeconomic feedbacks as well as an appropriate amount of system detail that resolves key variables and the relationships among them as they evolve over time. In this work, several features were incorporated into the EPPA model to explicitly represent physical system detail in the passenger vehicle transport sector. These features include an empirically-based parameterization of the relationship between income growth and demand for vehicle-miles traveled, a representation of fleet turnover, and opportunities for fuel use and emissions abatement. These model developments, which are embodied in the EPPA5-HTRN version of the model, are described in detail in Karplus (2011).

The representation of technology and its endogenous response to underlying cost conditions is particularly essential for analyzing policies, which typically act—directly or indirectly—through the relative prices of fuels or vehicles. The EPPA5-HTRN model includes many potential advanced vehicle types—the hydrogen fuel cell vehicle, natural gas vehicle, plug-in hybrid electric vehicle, and fuel cell electric vehicle—as advanced low carbon options that are not cost competitive in the model base year. In the present study we only include the plug-in hybrid electric vehicle (PHEV) as a representative potential near-term, low carbon advanced vehicle option, which runs on both gasoline and electricity. The PHEV itself is assumed to be 30% more expensive relative to the base year 2004 internal combustion engine (ICE)-only vehicle (a "markup" of 30%), and to drive an equivalent of 60% of its mileage on electricity alone. In addition to altering the relative cost of the PHEV and the ICE vehicle in proportion to their gasoline fuel requirement, fuel price increases can also induce investment in ICE-only vehicle efficiency, as described in Karplus (2011). Depending on the combined effects of these two responses, the cost gap between the ICE-only vehicle and PHEV may narrow and may eventually favor adoption of the PHEV. When initially adopted, the PHEV faces increasing returns to scale as parameterized in earlier work (Karplus *et al.*, 2010). This feature of the model captures the intuition that early deployment is more costly per unit (beyond the "markup," which is the assumed incremental cost of production at scale) until large production volumes have been reached. As the cost of producing PHEVs declines, these reductions also affect its cost relative to the ICE-only vehicle.

2.3 Representation of the CAFE Standards in the EPPA Model

A representative vehicle fuel economy standard was implemented in the EPPA5-HTRN model in order to simulate a policy constraint based on the U.S. CAFE Standards. A fuel economy standard is represented in the model as a constraint on the quantity of fuel required per mile of travel for a particular vehicle technology option. It is implemented as an auxiliary constraint that forces the model to simulate adoption of vehicle technologies that achieve the target fuel economy at the least cost.

The vehicle fuel economy constraint equation is shown in Equation 1. All future reductions are defined relative to the ratio of fuel Q_{f,t_0} to vehicle miles-traveled Q_{VMT,t_0} in the model benchmark year (t_0). Vehicle fuel economy as described in EPPA5-HTRN is expressed relative to fuel economy in 2005, which was an average of 25.2 miles per gallon or 9.3 L per 100 km for the new vintage of vehicles in the model (zero to five-year-old vehicles).[3] Targets set by policymakers are typically reported in the literature and popular press using unadjusted fuel consumption (or fuel economy) figures. Unadjusted fuel consumption refers to the fuel requirement per unit distance determined in laboratory tests, while adjusted figures reflect actual energy use on the road. To obtain adjusted on-road fuel economy, we divide the unadjusted numbers by 0.8, which is an approximation of the combined effect on-road adjustment factors applied by the EPA to city and highway test cycle estimates (EPA, 2006). The trajectory A_t is a fraction that defines allowable per-mile fuel consumption relative to its value in the model benchmark year in each future model period. The constraint requires that the on-road fuel consumption (FES_t) realized in each period remain below the target for that year by inducing investment in energy saving technology, which is a substitute for fuel. For instance a value of $\mathrm{A_t}$ = 0.5 in 2030 means that fuel consumption per mile traveled relative to the model benchmark year must decline by half.

$$FES_t \leq A_t \left(Q_{f,t_0}/Q_{VMT,t_0}\right) \tag{1}$$

For purposes of this analysis, we consider four policy trajectories through 2050, corresponding to four different rates of fuel economy improvement over the period 2017 to 2025. Due to the fact that the EPPA model forecasts in five-year time steps, the fuel economy standard was calculated to constrain fuel consumption to a level that reflects the stringency of the standard in each of the past five years, weighted by the contribution of each vehicle vintage to total new vehicle-miles traveled (VMT). The policy trajectories are shown in **Figure 1**. These paths correspond to year-on-year improvements in fuel economy of 3%, 4%, 5%, and 6% per year from 2017 to 2025 and holding constant thereafter. The year-on-year fuel economy increases correspond to a combined light-duty vehicle test-cycle fuel economy of approximately 46 mpg, 51 mpg, 55 mpg, and 60 mpg respectively for model year 2025 vehicles.[4]

3. ANALYSIS OF 2017 TO 2025 CAFE STANDARDS

A key question for policymakers is the relationship between the stringency of the standard and the cost of compliance, as well as between the welfare cost of policy and the gasoline (or CO_2 emissions) reduction achieved. To understand the relevance of the second point, a bit of theory is helpful. Many technology or behavioral strategies could be employed to reduce gasoline use and CO_2 emissions from passenger vehicles—raising vehicle efficiency is only one of them. Requiring reductions through ever tougher fuel economy standards will gradually exhaust the pool of available, off-the-shelf technology that can be employed to meet the energy

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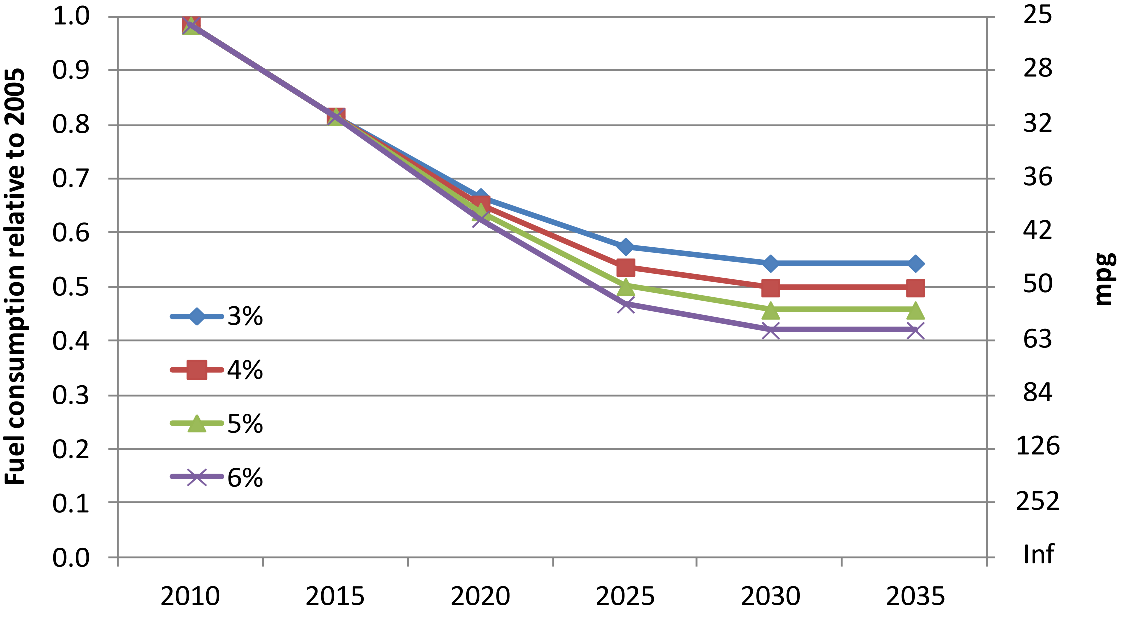
[3] Fuel economy or fuel consumption targets can be expressed either in miles per gallon or in liters per 100 km.

[4] It should be noted that these mpg-equivalents do not include downward adjustments that account for the contribution of air conditioning improvements to total GHG reductions, nor does it account for real-world driving conditions, which can reduce fuel efficiency by another 20%.

or environmental target. Although advanced technologies may be available, the cost of producing them will be high as well—at least initially—and is eventually non-linearly increasing, as discussed in previous work that considers both current and estimated near-term vehicle efficiency technology costs (EPA, 2010; Karplus, 2011). It is therefore important to consider how the average welfare cost per ton CO_2 abated and the associated total welfare loss change as the standard is tightened, to encourage careful choice of target stringency. Given that technology cost trajectories are uncertain, it is important to consider alternative technology cost scenarios under each level of standard stringency.



Note: Fuel economy is the equivalent test-cycle average fuel economy for zero to five-year-old vehicles.

Figure 1. Fuel economy trajectories for new (zero to five-year old vehicles) that assume different paces of year-on-year fuel economy improvement.

3.1 Analysis of Possible CAFE Standards at Varying Levels of Stringency

First we analyze the proposed CAFE Standards in the absence of a gasoline tax or other policy by considering 10 scenarios. We first model four proposed fuel economy standard paths, which correspond to a year-on-year increase in fuel economy of 3%, 4%, 5%, or 6%. We consider both high and low cost scenarios for an alternative fuel vehicle that could contribute significantly to meeting the fuel economy standard—a plug-in hybrid electric vehicle with 30% markup (high cost) or 10% markup (low cost) in the model base year 2004. We include two reference cases with either high or low alternative fuel vehicle costs. To compare the economic impacts of policies, we use private welfare loss measured as equivalent variation in constant discounted 2004 (discount rate is 4%), relative to the corresponding reference (No Policy) case.

A list of the scenarios with key assumptions and outcomes of interest is shown in **Table 1**. Cases (5) and (10) are baseline (No Policy) cases for both the high and low technology cost scenarios, and form the basis for comparison for the policy cases. Although a wide range of advanced vehicle technologies could be used to meet the standard, we focus on the PHEV as a representative low carbon technology. We consider the impact of the standard on cumulative fossil CO_2 emissions and gasoline use by light-duty vehicles, as well as its effects on technology characteristics—including improvement in conventional (internal combustion engine or ICE) vehicle fuel economy, adoption of the PHEV, and changes in VMT. As shown in columns (4) through (6), policies of different stringency result in different behavioral and technology responses. In both the high and low cost cases, the change in VMT (column 4) declines with increasing policy stringency, reflecting the net effect of per-mile fuel costs reductions (which tend to increase VMT relative to the No Policy reference), while vehicle capital cost increases due to the addition of technology to improve vehicle efficiency. Increases in vehicle capital cost would tend to delay or discourage new vehicle purchases, reducing VMT relative to the No Policy reference. The contribution of the PHEV to new (zero-to-five year-old vehicle) VMT increases with policy stringency (column 5), as does the average efficiency of remaining ICE vehicles in the new vehicle fleet (column 6), until the fuel economy target is achieved.

Table 1. Scenarios and key results from the range of fuel economy standard stringencies under low and high technology costs.

(1) Scenario Name	(2) FE % increase year-on-year	(3) PHEV cost	(4) % change VMT	(5) 2030 % PHEV in new VMT	(6) 2030 new ICE on-road mpg	(7) Cumulative CO_2 emissions 2010–2050 (bmt)	(8) Cumulative CO_2 reduced 2010–2050 (bmt)	(9) Cost per year 2010–2050 (NPV dis. $2004 billions)	(10) Cumulative welfare loss (NPV dis. $2004)
0% – Low	*No Policy*	*L*	*N.A.*	*10.3%*	*23.0*	*60.6*	*N.A.*	*N.A.*	*N.A.*
3% – Low	3	L	0.2%	22.6%	29.1	45.6	15.0	9.8	–0.16%
4% – Low	4	L	–0.1%	23.2%	31.1	43.9	16.7	17.3	–0.27%
5% – Low	5	L	–0.8%	23.6%	33.4	42.2	18.5	30.0	–0.47%
6% – Low	6	L	–2.1%	23.9%	36.2	40.4	20.3	53.0	–0.84%
0% – High	*No Policy*	*H*	*N.A.*	*0.3%*	*23.0*	*57.0*	*N.A.*	*N.A.*	*N.A.*
3% – High	3	H	0.6%	16.3%	30.4	45.9	11.1	8.5	–0.13%
4% – High	4	H	0.4%	16.8%	32.5	44.3	12.7	13.6	–0.21%
5% – High	5	H	0.0%	17.1%	35.1	42.8	14.2	21.9	–0.35%
6% – High	6	H	–0.8%	17.4%	38.0	41.2	15.8	36.5	–0.58%

Note: H – high PHEV cost, L – low PHEV cost, FE – fuel efficiency, NPV – net present value. Cumulative CO_2 emissions correspond to U.S. light-duty vehicle tank-to-wheels fossil CO_2 emissions (does not include electricity or other upstream fuel-related emissions). NA – Not applicable (provides a baseline case for comparison).

Depending on the cost of the representative alternative fuel vehicle (the PHEV), the baseline projections for gasoline use differ significantly. As shown in **Figure 2**, gasoline use continues to grow through 2050 in the low cost PHEV scenario in the absence of policy to reduce CO_2 emissions or petroleum use. In the high cost PHEV no policy scenario, gasoline use remains below 140 billion gallons per year and starts declining in 2035 in response to high vehicle and gasoline prices, which discourage travel demand. The peak and decline in gasoline use in the high cost case occurs in the absence of an inexpensive, efficient vehicle technology that would reduce the fuel required per mile of vehicle travel and enable continued demand growth. In all CAFE scenarios fuel use starts rising again in 2035, reflecting the fact that a constant fuel economy standard and rising population will translate into an increase in total demand for vehicles, travel, and fuel. Over the period 2015 to 2030, which corresponds to years when the tighter standards will make their largest impact through the introduction of significantly more efficient vehicles, gasoline use is reduced by about 25 billion gallons per year, or by about 19% over the entire period, assuming a 5% policy cost and high PHEV cost. Integrating over a longer time frame (2010 to 2050), a year-on-year 5% CAFE target achieves total cumulative reductions in light-duty vehicle gasoline use of around 30%.

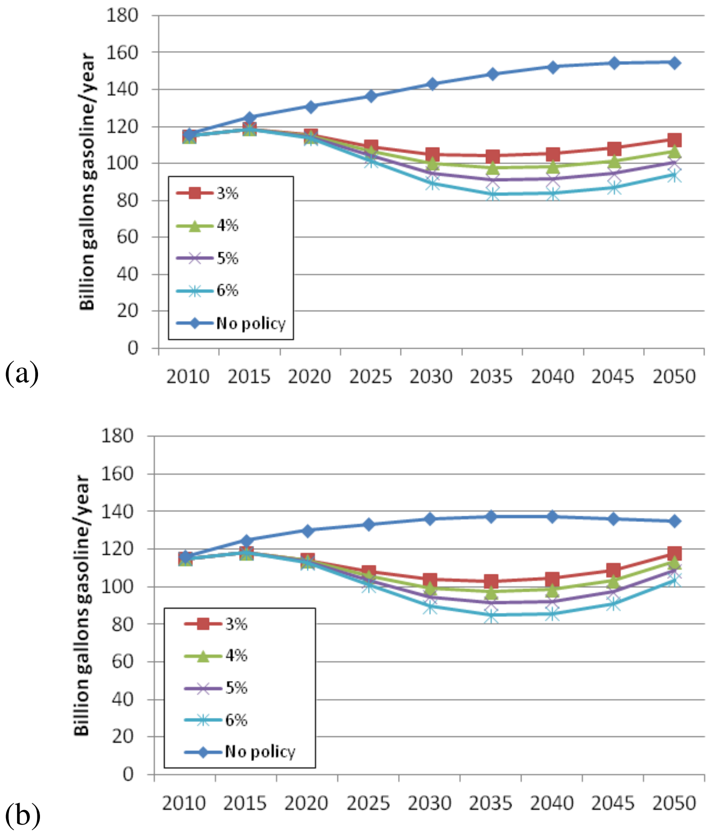


Figure 2. Projected gasoline consumption under an assumption of (a) low PHEV cost or (b) high PHEV cost. The 3%, 4%, 5%, and 6% policy cases represent targets for model year 2025 of 46 mpg, 51 mpg, 55 mpg, and 60 mpg, respectively.

We now turn to the results for CO_2 reduction and welfare impact. Using the 2015 to 2030 time frame cited above, the CO_2 emissions reduction achieved from light-duty vehicles is approximately 190 million metric tons per year, or 15% in cumulative terms, in the 5% policy case. Using a longer time frame, cumulative CO_2 reductions from light-duty vehicles over the period 2010 to 2050 is around 27%. In all cases, incremental increases in standard stringency produce additional cumulative reductions in CO_2 from light-duty vehicles. Larger CO_2 reductions incur ever larger average welfare costs over the range of standard stringency considered for the CAFE 2017 to 2025 compliance period. The early rise and then slight drop in average welfare cost in the high PHEV cost case corresponds to the fact that we represent economics of scale associated with PHEV production. When PHEV cost is high, the ICE-only vehicle maintains its advantage longer as policy becomes more stringent, while PHEV adoption and associated cost reductions with scale proceed more slowly (for more detail on the parameterization of PHEV adoption, see Karplus *et al.* (2010)). The fact that some of the proposed CAFE trajectories force action into the steeply increasing non-linear region at higher levels of required reductions suggests that, for the range of policy targets considered, less stringent targets are more cost effective on an average cost-per-ton basis, although they result in a smaller overall reduction in fuel use and CO_2 emissions.

The cost of abatement technology affects the outcomes of interest under the fuel economy standard. As shown in Table 1**,** when PHEV cost is low, it contributes more to overall abatement, and less abatement is required from the ICE-only vehicle. If PHEV cost is high, the opposite occurs, as ICE efficiency improvement and PHEV adoption compete with each other to contribute to reductions. Comparing average welfare costs in the two scenarios for technology costs under increasing levels of policy stringency suggests that the same policy will achieve a lower level of reduction in total light-duty vehicle CO_2 emissions when costs are high, relative to the case when abatement costs are low. **Figure 3** represents the welfare cost per ton of incrementally reducing CO_2 emissions through increases in the fuel economy standard in the year 2025. In the modeling analysis, a 6% year-on-year fuel economy policy with high PHEV cost actually achieves closer to the forecasted impact and average welfare cost of a 5% year-on-year fuel economy policy with low PHEV cost. This result reflects the fact that when vehicle efficiency improvements cost less, demand for that technology will increase in both the baseline and policy scenarios, and the cost of undertaking incremental CO_2 reductions under policy will increase relative to the baseline. Absolute CO_2 emissions in each of the policy cases also differ by a few percent depending on PHEV cost. As shown in column 7 of Table 1, taking the 5% year-on-year policy as an example, with high PHEV costs total cumulative CO_2 emissions reach 41.2 bmt, while with low PHEV costs they are only 40.4 bmt.

3.2 Combining CAFE Standards with a Gasoline Tax

We now consider what happens when fuel economy standards are combined with a gasoline tax. At least two rationales have been given for coupling a gasoline tax with a fuel economy standard. First, a moderate gasoline tax could help to offset increases in VMT demand that occur as a result of lower per-mile gasoline costs. Second, a gasoline tax will incentivize consumers to purchase high fuel economy vehicles, reducing the financial burden on automotive producers to price vehicles in a way that forces technology into the market when it would not otherwise be cost competitive.

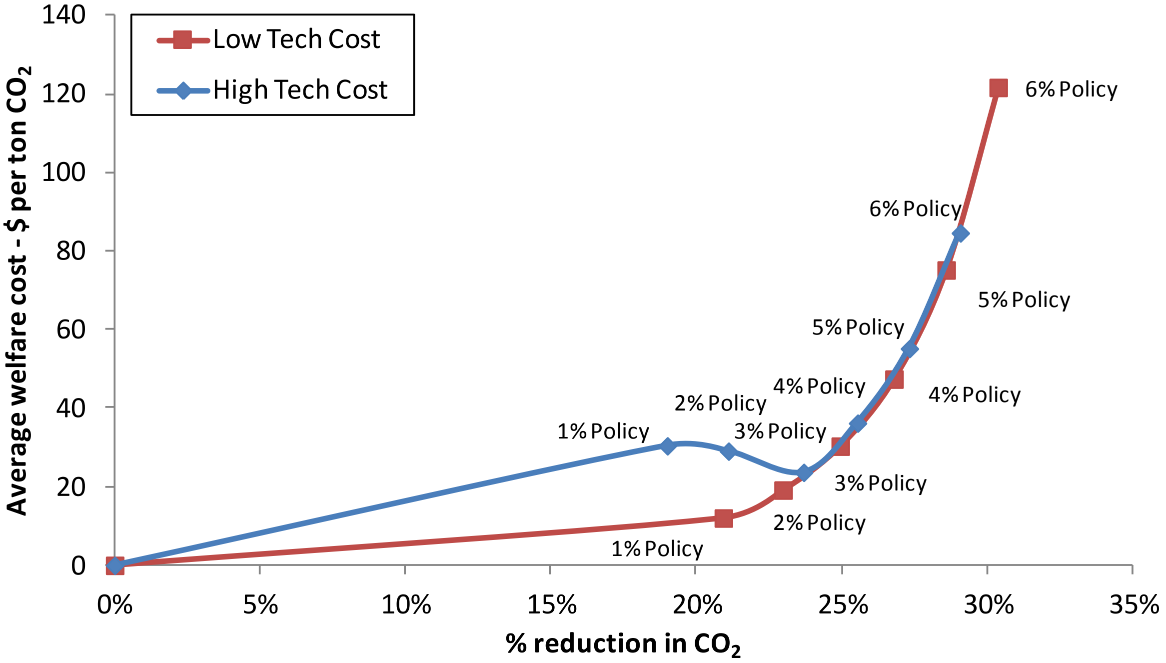


Figure 3. Average welfare cost in 2025 of CO_2 emissions reductions under varying levels of fuel economy standard stringency relative to BAU with same cost assumptions.

We focus on the 5% year-on-year CAFE policy under high and low technology cost conditions in the presence and absence of a 25% *ad valorem* gasoline tax, which is equivalent to an additional federal excise tax of about 50 cents per gallon in 2004 USD and increases over time as resource depletion or policy causes gasoline prices to rise endogenously in the model. Interestingly, the gasoline tax has the effect of reducing total VMT when technology costs are high (relative to a high cost technology baseline), while PHEV contribution to total VMT remains unchanged—and the burden on ICE-only vehicles to improve is reduced. We also considered sensitivity to higher tax levels (which are likely to be even less politically feasible) and found the same result.

An important result is that when combined with a fuel economy standard, the effect of the tax on CO_2 emissions and welfare could differ in sign depending on the cost of vehicle efficiency technology, as can be seen by comparing low and high technology cost scenarios for fuel economy standards with corresponding cases with a gasoline tax added in **Table 2**. When PHEVs are inexpensive, adding a gasoline tax actually offsets total vehicle CO_2 emissions reductions. By reducing total mileage in early periods, the potential contribution a PHEV could make in later periods to (low cost) CO_2 emissions reductions is also lower. As a result, the combined policies realize slightly less CO_2 reduction but also lower welfare loss. When PHEVs are costly, adding the tax to the fuel economy standard has a different effect—it reinforces the effect of high capital costs by raising fuel costs and further reducing travel relative to the No Policy baseline. The net effect is greater CO_2 emissions reductions relative to the CAFE standard alone, but also greater welfare loss due principally to a reduction in VMT.

Table 2. The impact of combining a CAFE Standard with a gasoline tax under low and high technology cost conditions.

Scenario Name	**FE % increase year-on-year**	**PHEV cost***	**% change VMT in 2030**	**2030 % PHEV in new VMT**	**2030 new ICE mpg**	**Cumulative CO_2 emissions (bmt)**	**Cumulative CO_2 reduced (bmt)**	**Cumulative welfare loss (NPV dis. $2004)**
0% – Low	*No Policy*	*L*	*N.A.*	*10.3%*	*23.0*	*60.6*	*N.A.*	*N.A.*
5% – Low	5	L	–0.8%	23.6%	33.4	42.2	18.5	–0.47%
5% – Low – T	5% + Tax	L	–0.1%	23.7%	33.4	42.5	18.1	–0.38%
0% – High	*No Policy*	*H*	*N.A.*	*0.3%*	*23.0*	*57.0*	*N.A.*	*N.A.*
5% – High	5	H	0.0%	17.1%	35.1	42.8	14.2	–0.35%
5% – High – T	5% + Tax	H	–0.8%	17.1%	33.4	41.9	15.1	–0.52%

Note: New ICE mpg refers to the average mpg for zero to five-year-old vehicles. Cumulative CO_2 reduced refers to the total over the period 2010 to 2050, assuming the 5% policy trajectory as shown in Figure 1.

This analysis underscores an interesting characteristic of the fuel economy standard. Under technology cost uncertainty, the amount of CO_2 emissions reduced relative to its respective No Policy baseline adjusts based on the cost of compliance. In this way, high cost conditions result in less abatement under policy, but this abatement is relative to a lower absolute baseline CO_2 emissions level. By contrast, when technology costs are low, significant abatement occurs relative to a higher absolute baseline CO_2 emissions level.

By contrast, a gasoline tax causes emissions to adjust in the opposite fashion. When PHEV technology costs are low, a tax will offset the rebound effect associated with inexpensive vehicle efficiency, reducing both emissions abatement and the associated welfare cost. When technology costs are high, the tax will add to the burden on consumers, who would have curbed fuel use in the absence of a tax because of the high cost associated with required fuel efficiency improvements. In this case, adding a tax increases both emissions abatement and welfare cost. Thus the net effect on CO_2 emissions and welfare of adding a fuel tax in the background of a fuel economy standard could be different in sign, depending on how the tax interacts with the underlying cost of the efficiency technology and consumers' propensity to trade off gasoline costs against investment in vehicle efficiency.

4. CONCLUSIONS

This work has investigated several proposed trajectories for the 2017 to 2025 model year CAFE standards. Over the period 2015 to 2030, a policy that requires a 5% year-on-year increase in fuel economy would reduce gasoline use by about 27 billion gallons per year, reduce CO_2 emissions by approximately 190 million metric tons per year, and cost $25 billion per year (net present value in 2004 USD) relative to a No Policy baseline. The actual rule will likely include additional flexibility provisions that may reduce the stringency of the required standard and offset both the reductions achieved and the associated costs.

Comparing the proposed policy paths, a less aggressive policy (3% year-on-year increase in fuel economy) has the lowest implicit discounted cost per ton of CO_2 reduced of the four policy trajectories under consideration (around $31 per ton). By contrast, a 5% policy has an implicit discounted cost per ton of CO_2 reduced of $65. This result reflects increasing technology costs, as well as the limits on the introduction of new technology due to fleet turnover and early stage deployment constraints for alternative fuel vehicles. However, the result generalizes to any case in which policy targets span a relatively steep, non-linearly increasing part of the marginal abatement cost curve. Costs increase with abatement and may exhibit a very steep curvature when the limit of currently available abatement technology is reached. While technological progress may contribute to cost reductions, realizing these cost reductions requires additional resources and time to develop and demonstrate promising early-stage technologies. Moreover, reducing CO_2 emissions from other sectors will be less costly than continuing to extract reductions from new light-duty vehicles, which enter the vehicle fleet gradually and incur relatively high technology costs per ton CO_2 reduced. Instead of pursuing ever tighter fuel economy standards, policies that encourage reductions from other sectors with relatively low costs of abatement should be considered.

This work also shows that depending on the cost of low-carbon substitutes for the internal combustion engine, fuel economy standards could result in different CO_2 emissions and welfare outcomes, relative to the appropriate baseline. Here we focus on the PHEV, and show that the availability of a low cost PHEV in the baseline case favors higher household demand for vehicle transport over the next 40 years, while a high cost PHEV would reduce this demand and also the role that alternative fuel vehicles and associated fuels could play. Under a fuel economy standard, less expensive technology could mean that there is more gasoline use and CO_2 emissions to reduce by mid-century relative to a high cost scenario, if additional constraints to curb increased demand are not implemented early on.

Finally, this study shows how the effect of combining a modest gasoline tax with a fuel economy standard on CO_2 emissions and welfare depends on how it interacts with technology costs as they evolve over time. An *ad valorem* tax may offset both welfare loss and CO_2 emissions reductions relative to the no-tax CAFE case if technology costs are high. In this case, the baseline projection reflects the impact of high gasoline prices, which induce increased investment in vehicle fuel efficiency. Adding a CAFE Standard encourages adoption of fuel efficiency technology, some of which was already pursued under the baseline. A tax reduces CO_2

emissions further still by encouraging a combination of demand reduction and technology adoption, both of which are expensive given that at the margin further reductions are very costly. However, under a low technology cost scenario, adding a tax offsets the rebound effect, reducing the CO_2 emissions reduction obtained but also the associated welfare loss. This analysis underscores the importance of considering interactions among vehicle regulation, vehicle purchase and use decisions, and the availability and cost of different fuels, when evaluating the energy, environmental, and economic impact of proposed policies.

The findings of this study suggest several directions for future work. First, this study has assumed that consumers consider the lifetime fuel costs and savings associated with their vehicle purchases, assumptions that when relaxed could yield different technology adoption, energy, and environmental outcomes. Alternative implied consumer discount rates could be tested to explore the interplay between policies that bear on either vehicle or fuel cost, under different assumptions about how consumers trade off future costs against present costs when making vehicle purchase decisions (Alcott and Wozny, 2010; Hassett and Metcalf, 1993). Second, ongoing work focused on the vehicle usage response to fuel prices (rebound effect) is needed to better understand how this response operates in the case of partial or zero gasoline vehicles. These observations can be used to parameterize models (such as the one used here) to better represent the consumer usage response to these technologies under baseline and policy scenarios.

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5. REFERENCES

Allcott, H. and N. Wozny, 2012: *Gasoline prices, fuel economy, and the energy paradox*. Cambridge, MA: Center for Economic and Environmental Policy Research, (http://web.mit.edu/ceepr/www/publications/workingpapers/2010-003.pdf).

An, F., and A. Sauer, 2004: *Comparison of passenger vehicle fuel economy and GHG emission standards around the world*. Washington, D.C.: Pew Center on Global Climate Change.

Anderson, S.T., I.W.H. Parry, J. Sallee, and C. Fischer, 2011: Fuel economy standards: Impacts, efficiency, and alternatives. *Review of Environmental Economics and Policy*, 5(1): 89–108.

Bezdek, R.H. and R.M. Wendling, 2005: Potential long-term impacts of changes in US vehicle fuel efficiency standards. *Energy Policy*, 33(3): 407–419.

Cheah, L., J. Heywood, and R. Kirchain, 2010: The energy impact of U.S. passenger vehicle fuel economy standards. 2010 IEEE International Symposium on Sustainable Systems and Technology (ISSST), 1–6.

DeCicco, J., 2010: A fuel efficiency horizon for U.S. automobiles (paper prepared for The Energy Foundation). Ann Arbor, MI: University of Michigan, (http://energy.umich.edu/info/pdfs/Fuel Efficiency Horizon FINAL.pdf).

Dimaranan, B. and R. McDougall, 2002: *Global trade, assistance, and production: The GTAP 5 data base*. Center for Global Trade Analysis, Purdue University: West Lafayette, Indiana.

EPA [U.S. Environmental Protection Agency], 2011: *EPA and NHTSA propose to extend the National Program to reduce greenhouse gases and improve fuel economy for cars and trucks*. U.S. Environmental Protection Agency: Washington, D.C., (http://www.epa.gov/otaq/climate/documents/420f11038.pdf).

EPA [U.S. Environmental Protection Agency], 2010: *Final rulemaking to establish light-duty vehicle greenhouse gas emission standards and Corporate Average Fuel Economy Standards: Joint technical support document*. U.S. Environmental Protection Agency: Washington, D.C.

EPA [U.S. Environmental Protection Agency], 2006 *Final technical support document: Fuel economy labeling of motor vehicle revisions to improve calculation of fuel economy estimates*. U.S. Environmental Protection Agency: Washington, D.C., (http://www.epa.gov/fueleconomy/420r06017.pdf).

EPA and NHTSA [U.S. Environmental Protection Agency and U.S. National Highway Transportation Safety Administration], 2010: *Interim joint technical assessment report: Light-duty vehicle greenhouse gas emission standards and Corporate Average Fuel Economy Standards for model years 2017-2025*. Washington, D.C.: U.S. Environmental Protection Agency and National Highway Transport Safety Administration: Washington, D.C., (http://epa.gov/otaq/climate/regulations/ldv-ghg-tar.pdf).

EPCA [Energy Policy and Conservation Act of 1975], 1998: (Pub. L. No. 94-163), 1975.

Goldberg, P. K. The effects of the corporate average fuel efficiency standards in the US. *The Journal of Industrial Economics*, 46(1):1–33.

Hassett, K.A. and G.E. Metcalf, 1993: Energy conservation investment: Do consumers discount the future correctly? *Energy Policy*, 21(6) 710–716.

Hertel, T, 1997: *Global trade analysis: Modeling and applications*. Cambridge University Press: Cambridge, United Kingdom.

Karplus, V.J., 2011: *Climate and energy policy for U.S. passenger vehicles: A technology-rich economic modeling and policy analysis.* Ph.D. Thesis, Engineering Systems Division, Massachusetts Institute of Technology, February.

Karplus, V.J., S. Paltsev and J.M. Reilly, 2010: Prospects for plug-in hybrid electric vehicles in the United States and Japan: A general equilibrium analysis. *Transportation Research Part A: Policy and Practice*, 44(8): 620–641.

MacKenzie, D., 2009: *Trends and drivers of the performance—fuel economy tradeoff in new automobiles.* Master of Science Thesis, Massachusetts Institute of Technology.

Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian, and M. Babiker, 2005: The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. MIT JPSPGC *Report 125*, August, 72 p. (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt125.pdf).

Shiau, C.S.N., J.J. Michalek, and C.T. Hendrickson, 2009: A structural analysis of vehicle design responses to Corporate Average Fuel Economy policy. *Transportation Research Part A*: *Policy and Practice*, 43(9–10): 814–828.

Small, K.A., and K. Van Dender, 2007: Fuel efficiency and motor vehicle travel: The declining rebound effect. *The Energy Journal*, 28(4): 25–51.

Stavins, R., 2006: Vintage-differentiated environmental regulation. *Stanford Law Journal*, 25(1): 29–63.

Whitefoot, K., M. Fowlie, and S. Skerlos, 2010: Evaluating U.S. reformed Corporate Average Fuel Economy Standards with endogenous product attributes (Working Paper). Haas School of Business, University of California at Berkeley: Berkeley, CA, (http://ei.haas.berkeley.edu/pdf/seminar/Whitefoot-Fowlie-Skerlos.pdf).

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